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FORM PTO-1390 (REV. 5-93)	U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE	ATTORNEY'S DOCKET NUMBER **10191/2233**
TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371		U S. APPLICATION NO. (If known, see 37 CFR 1.5) 10/049181

INTERNATIONAL APPLICATION NO.	INTERNATIONAL FILING DATE	PRIORITY DATE CLAIMED:
PCT/DE00/02527	**02 August 2000 (02.08.00)**	**06 August 1999 (06.08.99)**

TITLE OF INVENTION
PIEZOCERAMIC ACTUATOR AND METHOD FOR ITS MANUFACTURE

APPLICANT(S) FOR DO/EO/US
HENNEKEN, Lothar; GLOCK, Armin; and HACKENBERG, Juergen

Applicants herewith submit to the United States Designated/Elected Office (DO/EO/US) the following items and other information.

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☒ This is an express request to begin national examination procedures (35 U S C. 371(f)) immediately rather than delay examination until the expiration of the applicable time limit set in 35 U.S.C. 371(b) and PCT Articles 22 and 39(1)
4. ☒ A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.
5. ☒ A copy of the International Application as filed (35 U S.C. 371(c)(2))
   a. ☐ is transmitted herewith (required only if not transmitted by the International Bureau)
   b. ☒ has been transmitted by the International Bureau.
   c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US)
6. ☒ A translation of the International Application into English (35 U S C. 371(c)(2)).
7. ☒ Amendments to the claims of the International Application under PCT Article 19 (35 U S C 371(c)(3))
   a ☐ are transmitted herewith (required only if not transmitted by the International Bureau).
   b. ☐ have. been transmitted by the International Bureau.
   c. ☐ have not been made, however, the time limit for making such amendments has NOT expired.
   d. ☒ have not been made and will not be made.
8. ☐ A translation of the amendments to the claims under PCT Article 19 (35 U S.C. 371(c)(3)).
9. ☒ An oath or declaration of the inventor(s) (35 U S.C. 371(c)(4)) (unsigned)
10. ☒ A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

Items 11. to 16. below concern other document(s) or information included:

11. ☒ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
12. ☐ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
13. ☒ A **FIRST** preliminary amendment.
14. ☒ A substitute specification and marked-up version thereof.
15. ☐ A change of power of attorney and/or address letter
16. ☒ Other items or information: International Search Report (translated), Preliminary Examination Report and PCT/RO/101.

EXPRESS MAIL NO.: EL244510918

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17. ☒ The following fees are submitted:

Basic National Fee (37 CFR 1.492(a)(1)-(5)):

Search Report has been prepared by the EUROPEAN PATENT OFFICE or JPO $890.00

International preliminary examination fee paid to USPTO (37 CFR 1.482) $710.00

No international preliminary examination fee paid to USPTO (37 CFR 1.482) but international search fee paid to USPTO (37 CFR 1.445(a)(2)) $740.00

Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO $1,040 00

International preliminary examination fee paid to USPTO (37 CFR 1.482) and all claims satisfied provisions of PCT Article 33(2)-(4) $100 00

				CALCULATIONS	PTO USE ONLY
ENTER APPROPRIATE BASIC FEE AMOUNT =				$ 890	
Surcharge of $130 00 for furnishing the oath or declaration later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1 492(e)).				$	
Claims	Number Filed	Number Extra	Rate		
Total Claims	6 - 20 =	0	X $18 00	$ 0	
Independent Claims	2 - 3 =	0	X $84 00	$ 0	
Multiple dependent claim(s) (if applicable)			+ $280.00	$	
TOTAL OF ABOVE CALCULATIONS =				$ 890	
Reduction by ½ for filing by small entity, if applicable. Verified Small Entity statement must also be filed. (Note 37 CFR 1.9, 1 27, 1 28).				$	
SUBTOTAL =				$ 890	
Processing fee of $130 00 for furnishing the English translation later the ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1 492(f)) +				$	
TOTAL NATIONAL FEE =				$ 890	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3 28, 3.31). $40.00 per property +				$	
TOTAL FEES ENCLOSED =				$ 890	
				Amount to be: refunded	$
				charged	$

a. ☐ A check in the amount of $__________ to cover the above fees is enclosed.

b. ☒ Please charge my Deposit Account No. 11-0600 in the amount of **$890.00** to cover the above fees. A duplicate copy of this sheet is enclosed.

c. ☒ The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. 11-0600. A duplicate copy of this sheet is enclosed.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1 137(a) or (b)) must be filed and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO:
Kenyon & Kenyon
One Broadway
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Customer No. 26646

for Richard Mayer (by Jong Lee Reg. No. 36,197)
SIGNATURE

Richard L. Mayer, Reg No. 22,490
NAME

2/6/02
DATE

[10191/2233]

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant(s)	:	Lothar HENNEKEN et al.
Serial No.	:	To Be Assigned
Filed	:	Herewith
For	:	**PEIZOCERAMIC ACTUATOR AND METHOD FOR ITS MANUFACTURE**
Examiner	:	To Be Assigned
Group Art Unit	:	To Be Assigned

Assistant Commissioner for Patents
Washington, D.C. 20231

PRELIMINARY AMENDMENT AND
37 C.F.R. § 1.125 SUBSTITUTE SPECIFICATION STATEMENT

SIR:

Please amend the above-identified application before examination, as set forth below.

IN THE DRAWINGS:

Please amend the drawings as indicated in red ink on the attached sheet.

IN THE SPECIFICATION AND ABSTRACT:

In accordance with 37 C.F.R. § 1.121(b)(3), a Substitute Specification (including the Abstract but without claims) accompanies this response. It is respectfully requested that the Substitute Specification (and Abstract) be entered to replace the Specification of record.

IN THE CLAIMS:

Without prejudice, please cancel original claims 1-8 and cancel substitute claims 1-5. Please add new claims 9-14 as follows:

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--9. (New) A piezoceramic actuator comprising:

a monolithic stack of thin piezoceramic films; and

internal electrodes arranged between the films, the internal electrodes being electrically interconnected on outer sides of the stack to form at least two electrode groups electrically separated from one another, the internal electrodes each having a rail-like extension in a region of the outer side of the stack;

wherein each rail-like extension has one of electrochemically deposited nickel-alloy and nickel.

10. (New) The actuator according to claim 9, wherein each rail-like extension is made of nickel-alloy layer and a gold layer.

11. (New) The piezoceramic actuator according to claim 9, wherein each rail-like extension has one of electrolytically deposited nickel-alloy and nickel.

12. (New) The actuator according to claim 11, wherein each rail-like extension is made of nickel-alloy layer and an adjacent gold layer.

13. (New) A method for manufacturing a piezoceramic actuator having a monolithic stack of thin piezoceramic films and internal electrodes arranged between the films, the method comprising the steps of:

arranging the internal electrodes among the stack of piezoceramic films to form the monolithic stack;

connecting the internal electrodes as the cathode;

electrochemically depositing one of nickel and nickel-alloy to form rail-like extensions on the internal electrodes in a region of the outer side of the monolithic stack.

14. (New) The method according to claim 17, further comprising the step of:

electrochemically depositing gold to form the rail-like extensions.--

Remarks

This Preliminary Amendment cancels without prejudice original claims 1-8 and substitute claims 1-5 in the underlying PCT Application No. PCT/DE00/02527, and adds without prejudice new claims 9-14. The Preliminary Amendment conforms the claims to U.S. Patent and Trademark Office rules and do not add new matter to the application.

In accordance with 37 C.F.R. § 1.121(b)(3), the Substitute Specification (including the Abstract but without the claims) contains no new matter. The amendments reflected in the Substitute Specification (including Abstract) are to conform the Specification and Abstract to U.S. Patent and Trademark Office rules or to correct informalities. As required by 37 C.F.R. § 1.121(b)(3)(iii) and § 1.125(b)(2), a Marked Up Version Of The Substitute Specification comparing the Specification of record and the Substitute Specification also accompanies this Preliminary Amendment. Approval and entry of the Substitute Specification (including Abstract) is respectfully requested.

The underlying PCT Application No. PCT/DE00/02527 includes an International Search Report, dated December 18, 2000. The Search Report includes a list of documents that were uncovered in the underlying PCT Application. A copy of the Search Report accompanies this Preliminary Amendment.

The underlying PCT application also includes an International Preliminary Examination Report ("IPER") dated November 2, 2001. An English translation of the IPER is included herewith

Applicants assert that subject matter of the present invention is new, non-obvious, and useful. Prompt consideration and allowance of the application are respectfully requested.

Respectfully submitted,

KENYON & KENYON

Dated: February 6, 2002

By: for Richard Mayer by J Lee (Reg. No. 36,197)

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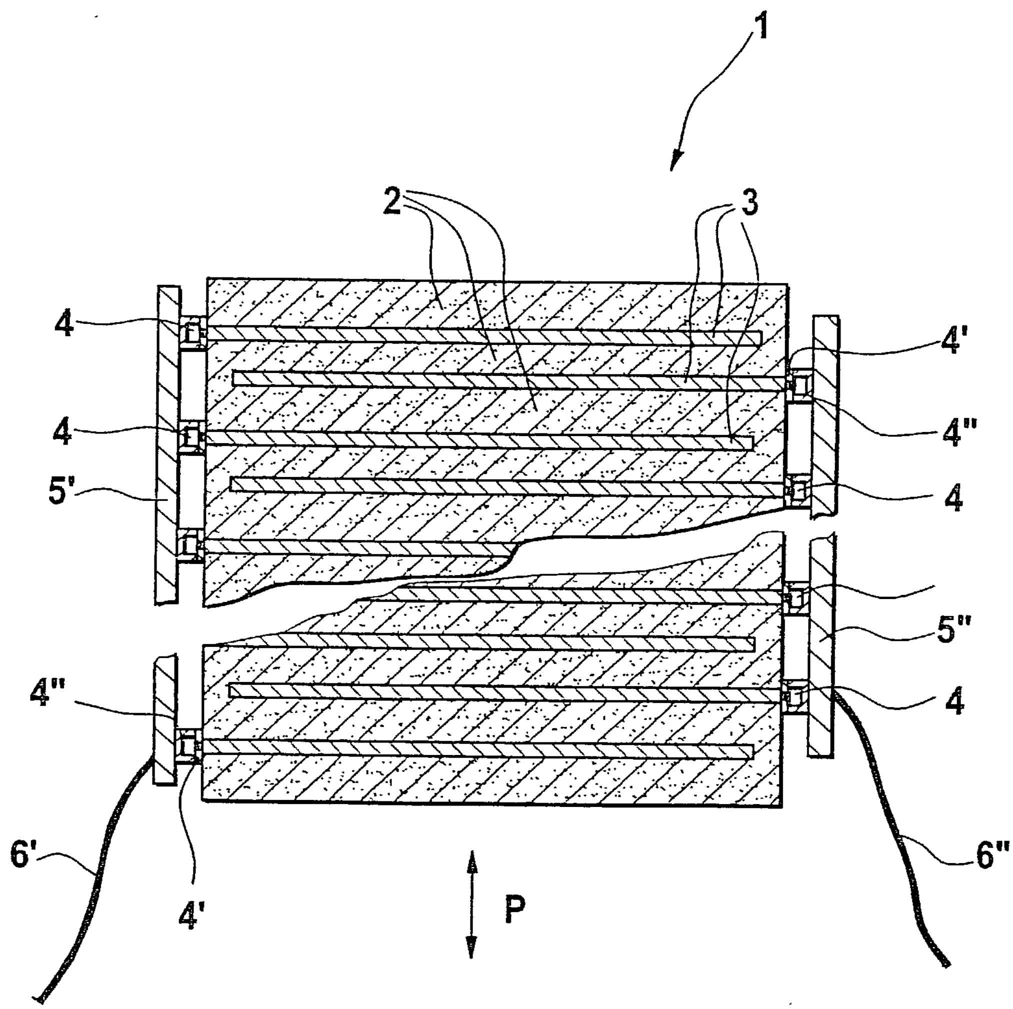

Figure 1

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PIEZOCERAMIC ACTUATOR AND METHOD FOR ITS MANUFACTURE

FIELD OF THE INVENTION

The present invention relates to a piezoceramic actuator, substantially made up of a sintered monolithic stack of thin piezoceramic films having internal electrodes, arranged between the films, that are electrically interconnected on the outer side of the stack to form at least two electrode groups, electrically separated from one another, having alternatingly successive internal electrodes of the at least two groups.

BACKGROUND OF THE INVENTION

Piezoceramic materials have the property of becoming electrically charged when impinged upon by mechanical forces, i.e. in particular under mechanical compression or tension. On the other hand, the result of an electric field applied to the piezoceramic material is that the material is mechanically distorted, i.e. expands or contracts.

These latter effects are utilized in actuators in order to perform positioning motions.

As a result of the construction of the actuator from a stack of piezoceramic films having a corresponding number of internal electrodes, a high electric field strength can be achieved within the piezoceramic films even with a limited electrical operating voltage, since in the case of two electrode groups, the operating voltage is present between each two adjacent internal electrodes.

Contacting of the internal electrodes can present practical difficulties. In conventional actuators, side regions of the stack that are separated from one another are metal-coated in such a way that the one coating is electrically connected to the internal electrodes of the one group, and the other

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coating is electrically connected to the internal electrodes of the other group.

Upon operation of the actuators, these metal coatings are exposed to considerable mechanical stresses when the actuator expands or contracts in accordance with the particular operating voltage. Large alternating stresses can occur in this context if the operating voltage is frequently switched on and off or is switched over in terms of its polarity.

These mechanical stresses in the metal coatings can result in cracks in the coating, with the consequence that a variable number of internal electrodes can no longer be connected to the operating voltage source and the adjacent piezoceramic films cannot, or essentially cannot, contribute further to the work of the actuator.

It is therefore proposed in German Patent 196 48 545 A1 to cover the aforesaid metal coatings with a further electrically conductive layer that is mechanically particularly flexible, in order to keep the fragments of the aforesaid coating -- which in German Patent 196 48 545 A1 are also referred to as the "base metallization" -- continuously in electrically conductive contact with one another. This additional coating can, for example, take the form of a knitted or braided wire structure, or that of a metal foam or corrugated sheet.

SUMMARY OF THE INVENTION

The present invention provides a piezoceramic actuator which has a stack of thin piezoceramic films having internal electrodes arranged between the films, each of the internal electrodes extending, at least on a region of the outer side of the stack, by way of rail-like or tab-like metal elements which preferably can be formed by electrolytically deposited metal. The internal electrodes can thereby be interconnected in electrically conductive fashion at a certain distance from the side edges of the piezoceramic films, for example by way of optionally corrugated metal films, knitted metal structures, or the like, or conductive plastic films, for

example silicone films into which electrically conductive particles are embedded, so that these films form a continuous planar electrically conductive ribbon.

The rails or tabs that extend the internal electrodes outside the piezoceramic stack thus form a noncontinuously structured, strip-shaped base metallization, these rails or tabs being little stressed, if at all, by the mechanical motions of the adjacent piezoceramic films during operation of the actuator. Because these rails or tabs are electrically interconnected in mechanically flexible fashion, a particularly strong actuator can be achieved.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows a cross-sectional view of an actuator according to the present invention.

DETAILED DESCRIPTION

According to Figure 1, a piezoceramic actuator 1 according to the present invention is substantially made up of a stack of sintered piezoceramic films 2 having arranged between them metallic internal electrodes 3 which extend alternately to the right and left side of actuator 1 that is depicted, i.e. are accessible from outside between the adjacent piezoceramic films 2. On the respectively opposite edge region, each internal electrode is covered by the adjacent piezoceramic films 2, so that the edge of the respective internal electrode 3 is inaccessible from the outside.

By electrolytic metal deposition (presented below), rail-like extensions 4, which for example are each made up of a nickel layer 4' directly adjacent to inner electrodes 3 and a gold layer 4" located externally thereabove, are shaped onto the externally accessible edge regions of inner electrodes 3 to the right and left in the drawing.

The exposed edges of rail-like extensions 4 are electrically interconnected via electrically conductive films 5' and 5"

which are made, for example, of plastic, e.g. silicone or copolymers, and electrically conductive carbon or metal particles embedded therein; in order to achieve the desired electrical conductivity, these particles are very densely packed, and the plastic material serves substantially to ensure mechanical bonding of the particles.

Rail-like extensions 4 and films 5' and 5" can be interconnected in electrically conductive fashion, for example, by hot pressing.

The two films 5' and 5" are in turn electrically connected to connector lines 6' and 6" through which films 5' and 5", and thus internal electrodes 3 electrically connected thereto, can be connected to an operating voltage source, in such a way that the group of internal electrodes 3 electrically connected to film 5', and internal electrodes 3 electrically connected to film 5" and engaging in comb fashion between the aforesaid internal electrodes 3, respectively have electrically opposite polarities, and each piezoceramic film 2 located therebetween is impinged upon by a corresponding electric field.

Depending on the polarity of the electrical operating voltage, the upper and lower ends of actuator 1 then perform motions relative to one another in accordance with arrow P.

Since films 5' and 5" are spatially separated from the edges of piezoceramic films 2, and since films 5' and 5" moreover possess a certain elastic flexibility, the motions of actuator 1 cannot cause any damage to films 5' and 5".

Films 5' and 5" may also exhibit a corrugated structure, in such a way that an externally convex ridge extends between each two internal electrodes 3 attached adjacently to film 5' or 5", and between their rail-shaped extensions 4.

Alternatively, it is also possible to replace the conductive films 5' and 5" with metal knitted structures or meshes, or also with a layer of metal foam.

Electrochemical production of rail-shaped extensions 4 can be accomplished as follows:

The stack of sintered piezoceramic films 2, having internal electrodes 3 arranged therebetween, is immobilized in a holder. Internal electrodes 3 are then electrically contacted to one another on the two opposite sides (in Figure 1, depicted on the right and left sides of the stack), but in such a way that the respective contacts still leave open a larger continuous region of the mutually opposite sides of the stack.

This is followed by cleaning of the stack in a neutral cleaner, for example at a temperature of 55°C and a treatment time of five minutes.

A rinse in demineralized water is then performed.

Electrochemical metal deposition is now performed, for example a nickel deposition or deposition of a nickel alloy from a nickel sulfamate electrolyte which, in the case of deposition of an alloy, contains corresponding additives or alloy components. A noble metal deposition from a corresponding electrolyte can optionally also be accomplished.

During deposition, internal electrodes 3 are electrically connected as the cathode via the aforesaid contacts of the stack, and a suitable anode is used.

The nickel sulfamate electrolyte can have a pH of between 3 and 4 and a temperature of approximately 40°C. Other electrolytes are operated under similar process conditions.

The electrical current intensity between cathode and anode can be 1 mA/cm^2 referred to the exposed ceramic surface. With this, a deposition rate of approx. 0.1 $\mu m/min$ is achieved.

After the production of metal layers 4', another rinse in demineralized water is performed.

A hard gold deposition in a gold electrolyte is then performed, internal electrodes 3 again being connected as the cathode; an anode of platinum-plated titanium can be used. The pH of the gold electrolyte can be set to a value of 4 to 5. The temperature can once again be 40°C. The current intensity can once again be 1 mA/cm^2 referred to the exposed ceramic surface of the ceramic film stack.

Alternatively, a uniform gold layer approx. 0.1 mm thick can also be deposited in electroless fashion from a hot gold electrolyte. The temperature for this method step can be between 80°C and 90°C.

Another rinse in demineralized water is then performed.

Rail-like extensions 4 are now available for connection to the electrically conductive films 5' and 5" or the like.

ABSTRACT

A piezoceramic actuator includes a monolithic stack of thin piezoceramic films having internal electrodes arranged between the films, and rail-like elements electrochemically shaped onto the internal electrodes on outer sides of the stack. The internal electrodes can thereby be interconnected, via a suitable conductive element, in electrically conductive fashion at a certain distance from the side edges of the piezoceramic films so that these films form a continuous planar electrically conductive ribbon.

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PIEZOCERAMIC ACTUATOR AND METHOD FOR ITS MANUFACTURE

[Background of the Invention] FIELD OF THE INVENTION

The present invention [refers] relates to a piezoceramic actuator, substantially made up of a sintered monolithic stack of thin piezoceramic films having internal electrodes, arranged between the films, that are electrically interconnected on the outer side of the stack to form at least two electrode groups, electrically separated from one another, having alternatingly successive internal electrodes of the at least two groups.

BACKGROUND OF THE INVENTION

[Actuators of this kind are commonly known.]

Piezoceramic materials have the property of becoming electrically charged when impinged upon by mechanical forces, i.e. in particular under mechanical compression or tension. On the other hand, the result of an electric field applied to the piezoceramic material is that the material is mechanically distorted, i.e. expands or contracts.

These latter effects are utilized in actuators in order to perform positioning motions.

As a result of the construction of the actuator from a stack of piezoceramic films having a corresponding number of internal electrodes, a high electric field strength can be achieved within the piezoceramic films even with a limited electrical operating voltage, since in the case of two electrode groups, the operating voltage is present between each two adjacent internal electrodes.

Contacting of the internal electrodes can present practical difficulties. In conventional actuators, side regions of the

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stack that are separated from one another are metal-coated in such a way that the one coating is electrically connected to the internal electrodes of the one group, and the other coating is electrically connected to the internal electrodes of the other group.

Upon operation of the actuators, these metal coatings are exposed to considerable mechanical stresses when the actuator expands or contracts in accordance with the particular operating voltage. Large alternating stresses can occur in this context if the operating voltage is frequently switched on and off or is switched over in terms of its polarity.

These mechanical stresses in the metal coatings can result in cracks in the coating, with the consequence that a variable number of internal electrodes can no longer be connected to the operating voltage source and the adjacent piezoceramic films cannot, or essentially cannot, contribute further to the work of the actuator.

It is therefore proposed in German Patent 196 48 545 A1 to cover the aforesaid metal coatings with a further electrically conductive layer that is mechanically particularly flexible, in order to keep the fragments of the aforesaid coating -- which in German Patent 196 48 545 A1 are also referred to as the "base metallization" -- continuously in electrically conductive contact with one another. This additional coating can, for example, take the form of a knitted or braided wire structure, or that of a metal foam or corrugated sheet.

[Advantages of the Invention] <u>SUMMARY OF THE INVENTION</u>

The present invention [is based on the general idea of] <u>provides a piezoceramic actuator which has a stack of thin piezoceramic films having internal electrodes arranged between the films,</u> [extending] each of the internal electrodes <u>extending</u>, at least on a region of the outer side of the stack, by way of rail-like or tab-like metal elements which preferably can be formed by electrolytically deposited metal. The internal electrodes can thereby be interconnected in

electrically conductive fashion at a certain distance from the side edges of the piezoceramic films, for example by way of optionally corrugated metal films, knitted metal structures, or the like, or conductive plastic films, for example silicone films into which electrically conductive particles are embedded, so that these films form a continuous planar electrically conductive ribbon.

The rails or tabs that extend the internal electrodes outside the piezoceramic stack thus form a noncontinuously structured, strip-shaped base metallization, these rails or tabs being little stressed, if at all, by the mechanical motions of the adjacent piezoceramic films during operation of the actuator. Because these rails or tabs are electrically interconnected in mechanically flexible fashion, a particularly strong actuator can be achieved.

[Drawing] BRIEF DESCRIPTION OF THE DRAWINGS

[A particularly preferred embodiment of the present invention will be explained with reference to the drawing.]

[The single] Figure 1 shows a [sectioned illustration] cross-sectional view of an actuator according to the present invention.

DETAILED DESCRIPTION

According to [the drawing] Figure 1, a piezoceramic actuator 1 according to the present invention is substantially made up of a stack of sintered piezoceramic films 2 having arranged between them metallic internal electrodes 3 which extend alternately to the right and left side of actuator 1 that is depicted, i.e. are accessible from outside between the adjacent piezoceramic films 2. On the respectively opposite edge region, each internal electrode is covered by the adjacent piezoceramic films 2, so that [there] the edge of the respective internal electrode 3 is inaccessible from the outside.

By electrolytic metal deposition (presented below), rail-like extensions 4, which for example are each made up of a nickel layer 4' directly adjacent to inner electrodes 3 and a gold layer 4" located externally thereabove, are shaped onto the externally accessible edge regions of inner electrodes 3 to the right and left in the drawing.

The exposed edges of rail-like extensions 4 are electrically interconnected via electrically conductive films 5' and 5" which are made, for example, of plastic, e.g. silicone or copolymers, and electrically conductive carbon or metal particles embedded therein; in order to achieve the desired electrical conductivity, these particles are very densely packed, and the plastic material serves substantially to ensure mechanical bonding of the particles.

Rail-like extensions 4 and films 5' and 5" can be interconnected in electrically conductive fashion, for example, by hot pressing.

The two films 5' and 5" are in turn electrically connected to connector lines 6' and 6" through which films 5' and 5", and thus internal electrodes 3 electrically connected thereto, can be connected to an operating voltage source, in such a way that the group of internal electrodes 3 electrically connected to film 5', and internal electrodes 3 electrically connected to film 5" and engaging in comb fashion between the aforesaid internal electrodes 3, respectively have electrically opposite polarities, and each piezoceramic film 2 located therebetween is impinged upon by a corresponding electric field.

Depending on the polarity of the electrical operating voltage, the upper and lower ends of actuator 1 then perform motions relative to one another in accordance with arrow P.

Since films 5' and 5" are spatially separated from the edges of piezoceramic films 2, and since films 5' and 5" moreover possess a certain elastic flexibility, the motions of actuator 1 cannot cause any damage to films 5' and 5".

Films 5' and 5" [can optionally] may also exhibit a corrugated structure, in such a way that an externally convex ridge extends between each two internal electrodes 3 attached adjacently to film 5' or 5", and between their rail-shaped extensions 4.

[Instead of this,] Alternatively, it is also possible to replace the conductive films 5' and 5" with metal knitted structures or meshes, or also with a layer of metal foam.

Electrochemical production of rail-shaped extensions 4 can be accomplished as follows:

The stack of sintered piezoceramic films 2, having internal electrodes 3 arranged therebetween, is immobilized in a holder. Internal electrodes 3 are then electrically contacted to one another on the two opposite sides (in Figure 1 [the drawing], depicted on the right and left sides of the stack [depicted]), but in such a way that the respective contacts still leave open a larger continuous region of the mutually opposite sides of the stack.

This is followed by cleaning of the stack in a neutral cleaner, for example at a temperature of 55°C and a treatment time of five minutes.

A rinse in demineralized water is then performed.

Electrochemical metal deposition is now performed, for example a nickel deposition or deposition of a nickel alloy from a nickel sulfamate electrolyte which, in the case of deposition of an alloy, contains corresponding additives or alloy components. A noble metal deposition from a corresponding electrolyte can optionally also be accomplished.

During deposition, internal electrodes 3 are electrically connected as the cathode via the aforesaid contacts of the stack, and a suitable anode is used.

The nickel sulfamate electrolyte can have a pH of between 3 and 4 and a temperature of approximately 40°C. Other electrolytes are operated under similar process conditions.

The electrical current intensity between cathode and anode can be 1 mA/cm^2 referred to the exposed ceramic surface. With this, a deposition rate of approx. 0.1 $\mu m/min$ is achieved.

After the production of metal layers 4', another rinse in demineralized water is performed.

A hard gold deposition in a gold electrolyte is then performed, internal electrodes 3 again being connected as the cathode; an anode of platinum-plated titanium can be used. The pH of the gold electrolyte can be set to a value of 4 to 5. The temperature can once again be 40°C. The current intensity can once again be 1 mA/cm^2 referred to the exposed ceramic surface of the ceramic film stack.

Alternatively, a uniform gold layer approx. 0.1 mm thick can also be deposited in electroless fashion from a hot gold electrolyte. The temperature for this method step can be between 80°C and 90°C.

Another rinse in demineralized water is then performed.

Rail-like extensions 4 are now available for connection to the electrically conductive films 5' and 5" or the like.

Abstract

A piezoceramic actuator [(1), which substantially comprises] includes a monolithic stack of thin piezoceramic films [(2)] having internal electrodes [(3)] arranged between the films, and rail-like elements [possesses rails (4),] electrochemically shaped onto the internal electrodes on outer sides of the stack[, with which contacting (5', 5") of the internal electrodes (3)is accomplished for operation of the actuator (1)]. The internal electrodes can thereby be interconnected, via a suitable conductive element, in electrically conductive fashion at a certain distance from the side edges of the piezoceramic films so that these films form a continuous planar electrically conductive ribbon.

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PIEZOCERAMIC ACTUATOR AND METHOD FOR ITS MANUFACTURE

Background of the Invention

The invention refers to a piezoceramic actuator, substantially made up of a sintered monolithic stack of thin piezoceramic films having internal electrodes, arranged between the films, that are electrically interconnected on the outer side of the stack to form at least two electrode groups, electrically separated from one another, having alternatingly successive internal electrodes of the at least two groups.

Actuators of this kind are commonly known.

Piezoceramic materials have the property of becoming electrically charged when impinged upon by mechanical forces, i.e. in particular under mechanical compression or tension. On the other hand, the result of an electric field applied to the piezoceramic material is that the material is mechanically distorted, i.e. expands or contracts.

These latter effects are utilized in actuators in order to perform positioning motions.

As a result of the construction of the actuator from a stack of piezoceramic films having a corresponding number of internal electrodes, a high electric field strength can be achieved within the piezoceramic films even with a limited electrical operating voltage, since in the case of two electrode groups, the operating voltage is present between each two adjacent internal electrodes.

Contacting of the internal electrodes can present practical difficulties. In conventional actuators, side regions of the stack that are separated from one another are metal-coated in such a way that the one coating is electrically connected to the internal electrodes of the one group, and the other

coating is electrically connected to the internal electrodes of the other group.

Upon operation of the actuators, these metal coatings are exposed to considerable mechanical stresses when the actuator expands or contracts in accordance with the particular operating voltage. Large alternating stresses can occur in this context if the operating voltage is frequently switched on and off or is switched over in terms of its polarity.

These mechanical stresses in the metal coatings can result in cracks in the coating, with the consequence that a variable number of internal electrodes can no longer be connected to the operating voltage source and the adjacent piezoceramic films cannot, or essentially cannot, contribute further to the work of the actuator.

It is therefore proposed in German Patent 196 48 545 A1 to cover the aforesaid metal coatings with a further electrically conductive layer that is mechanically particularly flexible, in order to keep the fragments of the aforesaid coating -- which in German Patent 196 48 545 A1 are also referred to as the "base metallization" -- continuously in electrically conductive contact with one another. This additional coating can, for example, take the form of a knitted or braided wire structure, or that of a metal foam or corrugated sheet.

Advantages of the Invention

The present invention is based on the general idea of extending each of the internal electrodes, at least on a region of the outer side of the stack, by way of rail-like or tab-like metal elements which preferably can be formed by electrolytically deposited metal. The internal electrodes can thereby be interconnected in electrically conductive fashion at a certain distance from the side edges of the piezoceramic films, for example by way of optionally corrugated metal films, knitted metal structures, or the like, or conductive plastic films, for example silicone films into which electrically conductive particles are embedded, so that these

films form a continuous planar electrically conductive ribbon.

The rails or tabs that extend the internal electrodes outside the piezoceramic stack thus form a noncontinuously structured, strip-shaped base metallization, these rails or tabs being little stressed, if at all, by the mechanical motions of the adjacent piezoceramic films during operation of the actuator. Because these rails or tabs are electrically interconnected in mechanically flexible fashion, a particularly strong actuator can be achieved.

Drawing

A particularly preferred embodiment of the present invention will be explained with reference to the drawing.

The single Figure shows a sectioned illustration of an actuator according to the present invention.

According to the drawing, a piezoceramic actuator 1 according to the present invention is substantially made up of a stack of sintered piezoceramic films 2 having arranged between them metallic internal electrodes 3 which extend alternately to the right and left side of actuator 1 that is depicted, i.e. are accessible from outside between the adjacent piezoceramic films 2. On the respectively opposite edge region, each internal electrode is covered by the adjacent piezoceramic films 2, so that there the edge of the respective internal electrode 3 is inaccessible from the outside.

By electrolytic metal deposition (presented below), rail-like extensions 4, which for example are each made up of a nickel layer 4' directly adjacent to inner electrodes 3 and a gold layer 4" located externally thereabove, are shaped onto the externally accessible edge regions of inner electrodes 3 to the right and left in the drawing.

The exposed edges of rail-like extensions 4 are electrically interconnected via electrically conductive films 5' and 5" which are made, for example, of plastic, e.g. silicone or

copolymers, and electrically conductive carbon or metal particles embedded therein; in order to achieve the desired electrical conductivity, these particles are very densely packed, and the plastic material serves substantially to ensure mechanical bonding of the particles.

Rail-like extensions 4 and films 5' and 5" can be interconnected in electrically conductive fashion, for example, by hot pressing.

The two films 5' and 5" are in turn electrically connected to connector lines 6' and 6" through which films 5' and 5", and thus internal electrodes 3 electrically connected thereto, can be connected to an operating voltage source, in such a way that the group of internal electrodes 3 electrically connected to film 5', and internal electrodes 3 electrically connected to film 5" and engaging in comb fashion between the aforesaid internal electrodes 3, respectively have electrically opposite polarities, and each piezoceramic film 2 located therebetween is impinged upon by a corresponding electric field.

Depending on the polarity of the electrical operating voltage, the upper and lower ends of actuator 1 then perform motions relative to one another in accordance with arrow P.

Since films 5' and 5" are spatially separated from the edges of piezoceramic films 2, and since films 5' and 5" moreover possess a certain elastic flexibility, the motions of actuator 1 cannot cause any damage to films 5' and 5".

Films 5' and 5" can optionally also exhibit a corrugated structure, in such a way that an externally convex ridge extends between each two internal electrodes 3 attached adjacently to film 5' or 5", and between their rail-shaped extensions 4.

Instead of this, it is also possible to replace the conductive films 5' and 5" with metal knitted structures or meshes, or also with a layer of metal foam.

Electrochemical production of rail-shaped extensions 4 can be accomplished as follows:

The stack of sintered piezoceramic films 2, having internal electrodes 3 arranged therebetween, is immobilized in a holder. Internal electrodes 3 are then electrically contacted to one another on the two opposite sides (in the drawing, on the right and left sides of the stack depicted), but in such a way that the respective contacts still leave open a larger continuous region of the mutually opposite sides of the stack.

This is followed by cleaning of the stack in a neutral cleaner, for example at a temperature of 55°C and a treatment time of five minutes.

A rinse in demineralized water is then performed.

Electrochemical metal deposition is now performed, for example a nickel deposition or deposition of a nickel alloy from a nickel sulfamate electrolyte which, in the case of deposition of an alloy, contains corresponding additives or alloy components. A noble metal deposition from a corresponding electrolyte can optionally also be accomplished.

During deposition, internal electrodes 3 are electrically connected as the cathode via the aforesaid contacts of the stack, and a suitable anode is used.

The nickel sulfamate electrolyte can have a pH of between 3 and 4 and a temperature of approximately 40°C. Other electrolytes are operated under similar process conditions.

The electrical current intensity between cathode and anode can be 1 mA/cm^2 referred to the exposed ceramic surface. With this, a deposition rate of approx. 0.1 μm/min is achieved.

After the production of metal layers 4', another rinse in demineralized water is performed.

A hard gold deposition in a gold electrolyte is then performed, internal electrodes 3 again being connected as the cathode; an anode of platinum-plated titanium can be used. The pH of the gold electrolyte can be set to a value of 4 to 5. The temperature can once again be 40°C. The current intensity can once again be 1 mA/cm^2 referred to the exposed ceramic surface of the ceramic film stack.

Alternatively, a uniform gold layer approx. 0.1 mm thick can also be deposited in electroless fashion from a hot gold electrolyte. The temperature for this method step can be between 80°C and 90°C.

Another rinse in demineralized water is then performed.

Rail-like extensions 4 are now available for connection to the electrically conductive films 5' and 5" or the like.

What is claimed is:

1. A piezoceramic actuator (1), substantially comprising a monolithic stack of thin piezoceramic films (2) having internal electrodes (3), arranged between the films, that are electrically interconnected on outer sides of the stack to form at least two electrode groups electrically separated from one another,

wherein the internal electrodes (3) each have rail-like extensions (4) on a region of the outer side of the stack.

2. The actuator as defined in Claim 1, wherein the extensions (4) are formed by electrolytically deposited metal.

3. The actuator as defined in Claim 1 or 2, wherein each rail-like extension (4) is made of a nickel or nickel-alloy layer (4') and an externally adjacent gold layer (4").

4. The actuator as defined in Claim 1 or 2, wherein each rail-like extension (4) is made of copper.

5. The actuator as defined in Claim 1 or 2, wherein each rail-like extension (4) is made of tin-silver alloys.

6. A method for manufacturing a piezoceramic actuator as defined in Claim 1, wherein the extensions (4) are produced electrochemically by the fact that the internal electrodes (3) are connected as the cathode and the monolithic stack is introduced into an electrolytic bath.

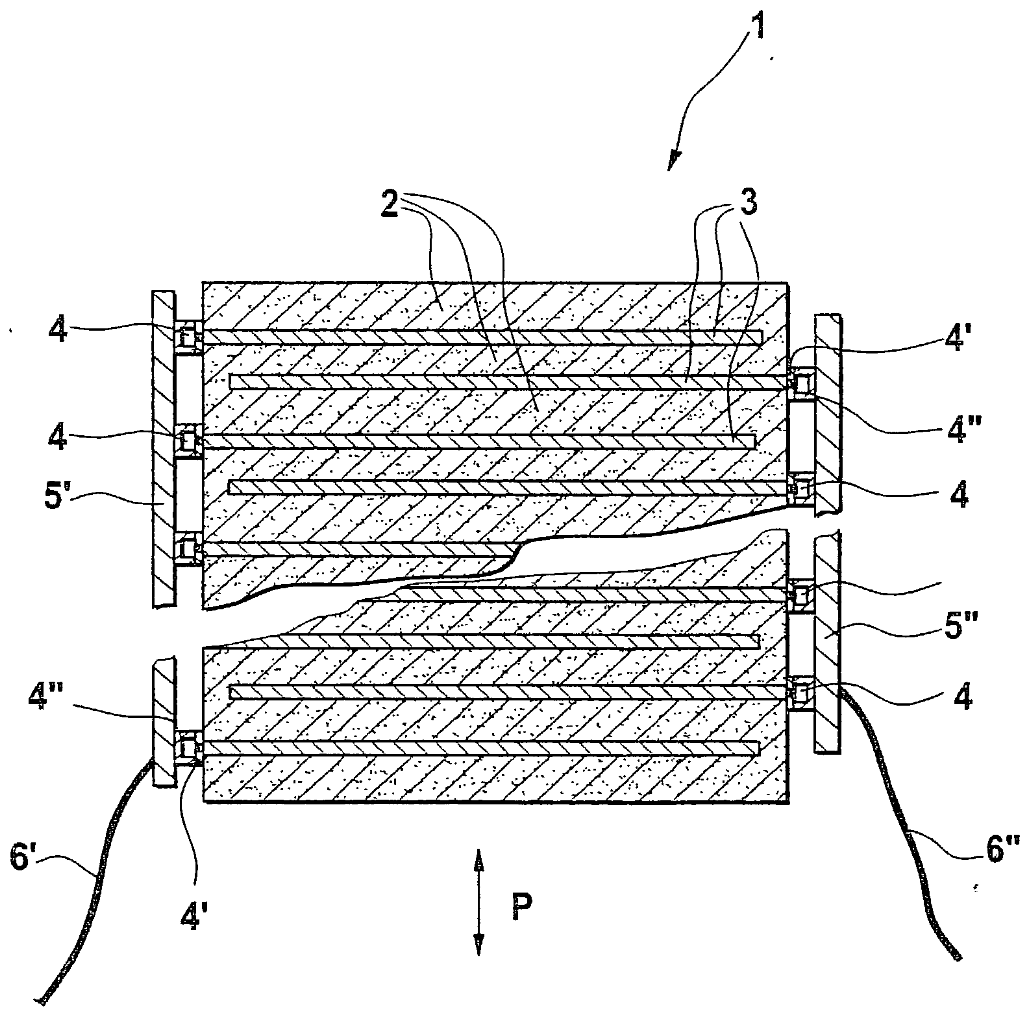
7. The method as defined in Claim 6, wherein in order to form the extensions (4), first nickel or nickel alloys and, in a further bath, gold are deposited.

8. The method as defined in Claim 6, wherein in order to form the extensions (4), copper or tin-

silver alloys are deposited.

Abstract

A piezoceramic actuator (1), which substantially comprises a monolithic stack of thin piezoceramic films (2) having internal electrodes (3) arranged between the films, possesses rails (4), electrochemically shaped onto the internal electrodes on outer sides of the stack, with which contacting (5', 5") of the internal electrodes (3) is accomplished for operation of the actuator (1).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COMBINED DECLARATION AND
POWER OF ATTORNEY FOR PATENT APPLICATION

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below adjacent to my name.

I believe I am an original, first and joint inventor of the subject matter which is claimed and for which a patent is sought on the invention entitled **PIEZOCERAMIC ACTUATOR AND METHOD FOR ITS MANUFACTURE** , and the specification of which:

[ ] is attached hereto;

[ ] was filed as United States Application Serial No. _______ on _________, 19__ and was amended by the Preliminary Amendment filed on ___________, 19__.

[x] was filed as PCT International Application Number PCT/DE00/02527, on the 2nd day of August, 2000.

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations, §1.56(a). I hereby claim foreign priority benefits under Title 35, United States Code § 119 of any foreign application(s) for patent or inventor's certificate or of any PCT international applications(s) designating at least one country other than the United States of America listed below and have also identified below any foreign application(s) for patent or inventor's certificate or any PCT international application(s) designating at least one country other than the United States of America filed by me on the same subject matter having a filing date before that of the application(s) of which priority is claimed:

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PRIOR FOREIGN/PCT APPLICATION(S)
AND ANY PRIORITY CLAIMS UNDER 35 U.S.C. § 119

Country : Federal Republic of Germany

Application No. : 199 36 713.2

Date of Filing: 6 August, 1999

Priority Claimed
Under 35 U.S.C. § 119 : [x] Yes [ ] No

I hereby claim the benefit under Title 35, United States Code § 120 of any United States Application or PCT International Application designating the United States of America that is/are listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in that/those prior application(s) in the manner provided by the first paragraph of Title 35, United States Code § 112, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations § 1.56(a) which occurred between the filing date of the prior application(s) and the national or PCT international filing date of this application:

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PCT INTERNATIONAL APPLICATIONS
DESIGNATING THE U.S. FOR BENEFIT UNDER 35 U.S.C. § 120

U.S. APPLICATIONS

Number :

Filing Date :

PCT APPLICATIONS
DESIGNATING THE U.S.

PCT Number :

PCT Filing Date :

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I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment or both under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

1-60

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